(12)   **EUROPEAN PATENT APPLICATION**

(72) Inventor: Xiang, Youqing
Canton, MI 48187 (US)

(74) Representative: Simons, Alison Diane
Dummett Copp
25 The Square
Martlesham Heath
Ipswich, Suffolk, IP5 3SL (GB)

(54)   **Control methods for electromagnetic valve actuators**

(57)   A method for initializing an actuator valve (12) and controlling the valve (12) using current command control (100) or voltage control including an estimate of back emf (200). According to the initialization method of the present invention, a series of low voltage pulses (304) is applied to one of the solenoid coils (20, 24) in the actuator valve (12) according to the natural frequency of the armature (16) movement in the actuator valve (12). The current command control method (100) of the present invention calculates a desired force (F_{em}) and divides the force into closing and opening components F_{em_c}, F_{em_o}, for calculating a desired current command Ic_cmd, Io_cmd, for each of the solenoid coils. The back emf control method (200) of the present invention divides the current signal into close and open components, I_o, I_c, that are individually processed and combined with a back emf estimate for each of the open and close solenoids, e_c, e_o. The result is a desired voltage command, V_c^*, V_o^*, for each of the solenoids that is communicated to the power stage (34) in order to operate the armature (16) as desired.
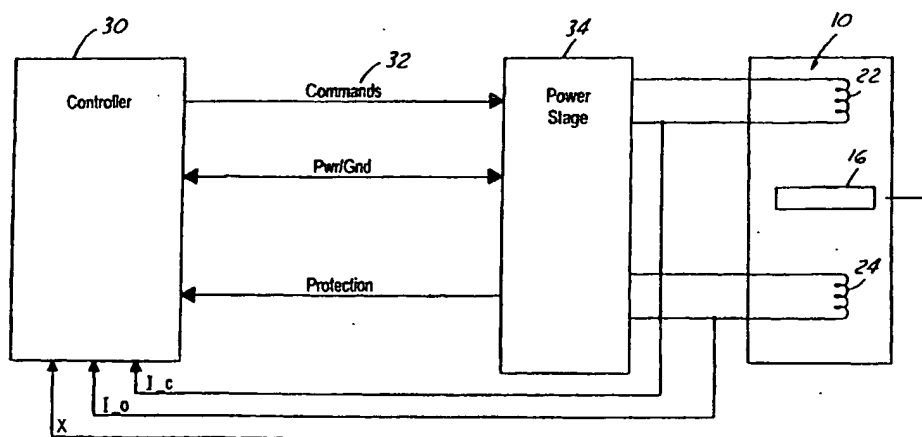
FIG. 2

EP 1 172 527 A3

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EUROPEAN SEARCH REPORT

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
A	EP 0 973 177 A (BAYERISCHE MOTOREN WERKE AG) 19 January 2000 (2000-01-19) * paragraph '0001! * * paragraph '0044! - paragraph '0047! *	1-5	F01L9/04
A	DE 195 44 207 A (UNIV DRESDEN TECH) 5 June 1997 (1997-06-05) * page 1, line 3,4 * * page 1, line 48 - page 2, line 8 *	1,3	
A	EP 0 810 350 A (TOYOTA MOTOR CO LTD) 3 December 1997 (1997-12-03) * column 1, line 7-11 * * column 1, line 54 - column 2, line 13 * * column 8, line 51 - column 9, line 27 *	4-6	
A	EP 1 001 142 A (DAIMLER CHRYSLER AG) 17 May 2000 (2000-05-17) * paragraph '0001! * * paragraph '0036! - paragraph '0040! *	4-6	
A	EP 0 908 904 A (HUSCO INT INC) 14 April 1999 (1999-04-14) * paragraph '0001! * * paragraph '0016! * * figure 6 *	4,5	TECHNICAL FIELDS SEARCHED (Int.Cl.7) F01L H01F G05B G01R G01D
A	US 5 589 749 A (DAVIDSON DALE D ET AL) 31 December 1996 (1996-12-31) * column 1, line 7-10 * * column 2, line 29 - column 3, line 5 *	4,5	
X	DE 198 51 679 C (DAIMLER CHRYSLER AG) 31 May 2000 (2000-05-31) * column 1, line 3-5 * * column 2, line 56-58 *	7,8	

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The present search report has been drawn up for all claims

Place of search	Date of compilation of the search	Examiner
THE HAGUE	15 April 2003	Paquay, J

European Patent Office

EUROPEAN SEARCH REPORT

Application Number

EP 01 11 6320

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
A	WO 99 25960 A (DAIMLER CHRYSLER AG ;STOLK THOMAS (DE); VON GAISBERG ALEXANDER (DE) 27 May 1999 (1999-05-27) * page 1, paragraph 1 * * page 1, paragraph 3 *	7,8	
A	DE 197 36 137 C (DAIMLER BENZ AG) 1 October 1998 (1998-10-01) * column 1, line 3-5 * * column 2, line 63 - column 3, line 1 * * column 3, line 10-17 *	7,8	
A	US 4 544 986 A (BUECHL JOSEF) 1 October 1985 (1985-10-01) * column 1, line 9-13 * * column 2, line 57-63 * * column 4, line 4-20 *	7,8	

TECHNICAL FIELDS
SEARCHED   (Int.Cl.7)

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	15 April 2003	Paquay, J

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Office

CLAIMS INCURRING FEES

The present European patent application comprised at the time of filing more than ten claims.

☐ Only part of the claims have been paid within the prescribed time limit. The present European search report has been drawn up for the first ten claims and for those claims for which claims fees have been paid, namely claim(s):

☐ No claims fees have been paid within the prescribed time limit. The present European search report has been drawn up for the first ten claims.

LACK OF UNITY OF INVENTION

The Search Division considers that the present European patent application does not comply with the requirements of unity of invention and relates to several inventions or groups of inventions, namely:

see sheet B

☒ All further search fees have been paid within the fixed time limit. The present European search report has been drawn up for all claims.

☐ As all searchable claims could be searched without effort justifying an additional fee, the Search Division did not invite payment of any additional fee.

☐ Only part of the further search fees have been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the inventions in respect of which search fees have been paid, namely claims:

☐ None of the further search fees have been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the invention first mentioned in the claims, namely claims:

European Patent Office

LACK OF UNITY OF INVENTION
SHEET B

Application Number

EP 01 11 6320

The Search Division considers that the present European patent application does not comply with the requirements of unity of invention and relates to several inventions or groups of inventions, namely:

1. Claims: 1-6

   Methods for generating commands to a controller for an electromagnetic valve actuator

2. Claims: 7,8

   A method for initializing an actuator valve

ANNEX TO THE EUROPEAN SEARCH REPORT
ON EUROPEAN PATENT APPLICATION NO.

EP 01 11 6320

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15-04-2003

Patent document cited in search report		Publication date	Patent family member(s)		Publication date
EP 0973177	A	19-01-2000	DE	19906437 A1	17-08-2000
			DE	19832198 A1	20-01-2000
			EP	0973177 A2	19-01-2000
DE 19544207	A	05-06-1997	DE	19544207 A1	05-06-1997
EP 0810350	A	03-12-1997	JP	9317419 A	09-12-1997
			CN	1169538 A ,B	07-01-1998
			DE	69707060 D1	08-11-2001
			DE	69707060 T2	11-07-2002
			EP	0810350 A1	03-12-1997
			KR	271903 B1	01-12-2000
			US	5889405 A	30-03-1999
EP 1001142	A	17-05-2000	DE	19852655 A1	25-05-2000
			EP	1001142 A2	17-05-2000
			US	6234122 B1	22-05-2001
EP 0908904	A	14-04-1999	US	5942892 A	24-08-1999
			BR	9803872 A	23-11-1999
			CA	2247809 A1	06-04-1999
			CN	1215160 A	28-04-1999
			EP	0908904 A2	14-04-1999
			JP	2973405 B2	08-11-1999
			JP	11153247 A	08-06-1999
US 5589749	A	31-12-1996	AU	3542595 A	22-03-1996
			EP	0778964 A1	18-06-1997
			WO	9607127 A1	07-03-1996
DE 19851679	C	31-05-2000	DE	19851679 C1	31-05-2000
WO 9925960	A	27-05-1999	DE	19750228 C1	03-12-1998
			BR	9814178 A	26-09-2000
			CN	1277655 T	20-12-2000
			WO	9925960 A1	27-05-1999
			EP	1030961 A1	30-08-2000
			JP	2001523787 T	27-11-2001
			US	6260522 B1	17-07-2001
DE 19736137	C	01-10-1998	DE	19736137 C1	01-10-1998
			WO	9909313 A1	25-02-1999
			EP	1005612 A1	07-06-2000
US 4544986	A	01-10-1985	DE	3307683 C1	26-07-1984
			DE	3362302 D1	03-04-1986

EPO FORM P0459

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ANNEX TO THE EUROPEAN SEARCH REPORT
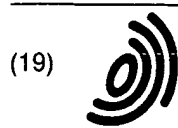ON EUROPEAN PATENT APPLICATION NO.   EP 01 11 6320

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
The members are as contained in the European Patent Office EDP file on
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15-04-2003

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 4544986 A		EP 0118591 A1	19-09-1984
		JP 1009827 B	20-02-1989
		JP 1528107 C	30-10-1989
		JP 59162759 A	13-09-1984

EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

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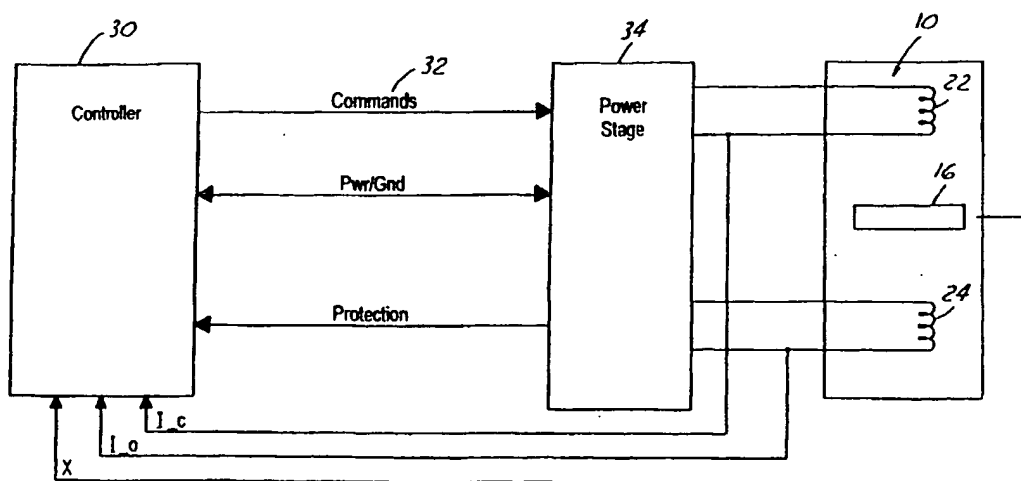
FIG. 2

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TECHNICAL FIELD

[0001] The present invention relates generally to controlling an electromagnetic valve actuator, and more particularly to control methods for electromagnetic engine valve actuation with variable timing to improve combustion control and fuel economy for an internal combustion engine.

BACKGROUND OF THE INVENTION

[0002] Typically in an internal combustion engine, the intake and exhaust valves are controlled mechanically. The valves are tied to the engine's crankshaft and thus there is limited flexibility in the control of the valves. Valve control is extremely important for optimizing fuel economy and reducing polluting emissions. Therefore, flexibility is highly desirable in valve control.

[0003] It is known in the art to employ electromagnetically driven valve actuators in an internal combustion engine. Typically, these known systems require power circuits having high frequency switching devices in order to handle the voltage differences required to properly control the valves. Additionally, the control of the valve timing is critical and therefore, is the subject of much consideration.

[0004] Improving the timing of the electromagnetically driven valves not only improves the engine's combustion capabilities, but may also reduce the pumping losses for air charging, thereby improving fuel economy and reducing emissions. Determination of the optimum current that should be applied to the opening and/or closing coils, and reducing the amount of excitation current that is required, are ongoing subjects of research.

BRIEF SUMMARY OF THE INVENTION

[0005] It is an object of the present invention to control the electromagnetic engine valve actuation system using current-commanded control. It is another object of the present invention to use back electromotive force (emf) to compensate for nonlinear feedback control.

[0006] It is a further object of the present invention to provide an initialization sequence for the above mentioned control techniques that reduces the amount of initialization current required by an actuator.

[0007] In carrying out the above objects and other objects and features of the present invention, a method is provided that improves the timing of an electromagnetic valve actuator by improving the valve control. In one embodiment of the present invention, a desired current is calculated based on feedback from the actuator and a power circuit generates the desired current in order to produce the force necessary to operate the actuator. In another embodiment of the present invention the current control method is enhanced by applying estimated back emf in order to calculate a desired voltage. The desired voltage is used to generate the voltage necessary to obtain the desired current, which will ultimately control the actuator. The back emf method of the present invention eliminates the need for any current regulation in the power stage, thereby reducing the size, complexity and ultimately the cost of the power stage.

[0008] Additionally an initialization method is provided which reduces the amount of current required to initialize a coil of the actuator. According to the initialization method of the present invention, a sequence of pulses is applied to the closing coil at predetermined intervals in order to enhance the natural frequency of oscillations and thereby generate a sufficient initialization pulse without the need for excessive current. Smaller current requirements will allow a reduction in the size of the closing coil to be realized, thereby increasing packaging space for other applications and at the same time reduce the weight and cost of the electromagnetic valve system.

[0009] Other objects and advantages of the invention will become apparent upon reading the following detailed description and appended claims, and upon reference to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] For a more complete understanding of this invention, reference should now be had to the embodiments illustrated in greater detail in the accompanying drawings and described below by way of examples of the invention. In the drawings:

[0011] FIGURE 1 is a sectional view of an electromagnetically driven intake valve, which is controlled according to an embodiment of the present invention;

[0012] FIGURE 2 is a schematic diagram of the electromagnetically driven actuator system controlled according to an embodiment of the present invention;

[0013] FIGURE 3 is a flow diagram of the current commanded control method of the present invention;

[0014] FIGURE 4 is a flow diagram of the back emf compensated voltage control method of the present invention;

[0015] FIGURE 5 is a graph of the flux linkage vs. the current for the back emf estimator;

[0016] FIGURE 6 is a graph showing the armature position response according to the initialization method of the present invention; and

[0017] FIGURE 7 is a graph showing the excitation voltage for either the opening coil, or the closing coil, according to the initialization method of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0018] Figure 1 depicts an electromagnetically driven actuator 10 used in conjunction with any of the control methods of the present invention. The actuator 10 has

a valve element 12 having a valve stem 14 which has an armature 16 secured thereto. The valve element 12 is slideably mounted in an engine head 18 of a cylinder block (not shown) of an internal combustion engine (not shown). It should be noted that while an intake valve is shown in Figure 1, the present invention is as applicable to an exhaust valve (not shown). The exhaust valve is similar in construction to the intake valve, except the valve element is mounted in the cylinder block at a location above the engine head for opening and closing an exhaust port.

[0019]   Referring still to Figure 1, the valve element 12 is driven by two opposing solenoids 20, 24. The solenoids 22, 24 are opposed to each other in a longitudinal direction. A closing solenoid 20 biases the valve element 12 in a valve closing direction. An opening solenoid 24 biases the valve element in a valve opening direction. The closing solenoid (20) has a core 21 and a coil 22. Likewise the opening solenoid (24) has a core 25 and a coil 26. A spring means 23 is interposed between the closing core 21 and the armature 16. Also, a spring means 27 is interposed between the opening core 25 and the armature 16. The force of spring means 23 and 27 becomes zero when the armature 16 is positioned in a balanced, or neutral, position. The spring means 23 and 27 act to bias the position of the valve element 12 in the opening direction when the armature 16 is positioned upward of the neutral position. And, the spring means 23 and 27 act to bias the position of the valve element 12 in the closing direction when the armature 16 is positioned downward of the neutral position.

[0020]   Selectively energizing the closing and opening solenoids with a driving current will move the valve element between a fully closed and a fully open position. When neither coil is energized, the valve element remains in a neutral position, intermediate a fully open position and a fully closed position.

[0021]   Figure 2 schematically shows the arrangement of an entire control system according to any embodiment of the present invention, incorporating the electromagnetic valve 12 shown in Figure 1. A controller 30 controls the motion of the actuator 10 and the transitions between the fully open and fully closed positions for the valve element. The controller 30 provides commands 32 to a power stage 34 that feeds the correct current and voltage to the open and close solenoids 20 and 24 in the actuator valve. Feedback in the form of opening coil current I_o, closing coil current, I_c and armature position, X, are provided by sensors, not shown, to the controller 30. Any of the embodiments for the control methods described herein can be implemented using the actuator system shown in Figure 2. It should also be noted that the power stage 34 could include the capability to regulate current.

[0022]   Figure 3 is a flow diagram of the current-commanded control method 100 of the present invention. As discussed above, the power stage (not shown in Figure

3) has current regulation capabilities to regulate the current supplied to the actuator according to the desired current calculated using this embodiment of the present invention. The current-command control method 100 is executed within the controller of the actuator system. The controller is supplied with the armature position, X, and input from a reference generator 102. The reference generator 102 provides a waveform that is stored in the memory of the controller and represents a profile of the preferred motion of the armature. Typically a sinusoidal profile is preferred.

[0023]   The armature position feedback, X, and the waveform from the reference generator 102 are summed 104 and processed by a proportional-integral-derivative (PID) controller 106 to generate a force, F_A, that represents the force required to move the armature. A spring coefficient, K_spring, provides an estimate of the spring force that must be overcome in order to move the armature. Finally, the output of the reference generator is processed 108 in order to estimate the accelerated force due to the mass of the armature, F_B. These three forces, F_A, K_spring, and F_B are combined 110 to determine a desired force, F_{em}, which is the electromagnetic force needed to move the armature as desired. The desired force is divided 112 into two components, a closing force, F_{em_c}, and an opening force, F_{em_o}. The division is made based on the sign of the component. The positive component represents the closing force and the negative component represents the opening force. Each component of the force is individually processed 114 in conjunction with a fixed constant, FRC_c1, which is generated using a model of the actuator. One skilled in the art is capable of generating this constant, and therefore, the mechanics will not be described herein.

[0024]   The method 100 of the present invention produces 116 two current commands. A closing current-command, Ic_cmd, is generated by manipulation of the closing force component of the desired force. An opening current-command, Io_cmd, is generated by manipulation of the opening force component of the desired force. Referring back to figure 2, these two current commands are communicated from the controller 30 to the power stage 34 by way of the commands 32 in order to provide the actuator 10 with the current necessary to move the armature as desired.

[0025]   Figure 4 is a flow diagram of another embodiment of the present invention, and provides an enhancement of the current-commanded method. The method is a back emf voltage control method 200. The back emf voltage control method 200 controls the power stage such that a voltage, v_c^* and v_o^*, is generated to obtain a desired voltage calculated in the controller. In the present embodiment, 200, the need for a current regulator in the power stage is eliminated. The back emf voltage control method 200 of the present invention provides more flexibility in the controller.

[0026]   The armature position feedback, X_{fb}, and a

waveform from a reference generator 202 are summed 204 and processed 206 by a PI controller. As in the current command method discussed above the current is divided 210 into two components, I_c^* and I_o^*. However, in this embodiment, a current reference generator 208 is used to divide the current. Feedback current for each of the coils, I_{c-fb} and I_{o-fb}, is fed 212 into individual PI controllers 214, 216. The output is summed 218 with outputs e_o and e_c from a back emf estimator 220. The result is a desired voltage component for each of the coils, v_c^* and v_o^* being provided to the controller for producing the command voltage needed to actuate the valve.

[0027]   According to the back emf voltage control method 200, the back emf in each coil is estimated 220 and used to calculate 222 a desired voltage. The desired voltage is communicated to the power stage, where the power stage generates the commanded voltage. The current is regulated by software in the controller.

[0028]   There are several ways to estimate 220 the back emf. In particular, one method that can be used is to store the flux linkage, Ψ, for the closing coil as a function of armature position and coil current. The flux linkage is stored as a two-dimensional look up table and can be shown graphically 228, as in Figure 5. The x-axis represents the current, I, and the y-axis represents the flux linkage, Ψ. The curves 230, 232, 234, and 236 represent the armature position. At two sampling points, there is shown $x_{fb}(k)$, $x_{fb}(k+1)$, $I_{c-fb}(k)$, and $I_{c-fb}(k+1)$. From the look-up table, there is:

$$\Psi_1 = \Psi(I_{c-fb}(k), x_{fb}(k))$$

$$\Psi_2 = \Psi(I_{c-fb}(k+1), x_{fb}(k)),$$

and

$$\Psi_3 = \Psi(I_{c-fb}(k+1), x_{fb}(k+1))$$

[0029]   The back emf is represented by the formula:

$$e_c = \frac{\Psi_3 - \Psi_2}{\Delta t}$$

where Δt is the sampling period. The same method can be used to estimate the open coil back emf, e_o.

$$e_o = \frac{\Psi(I_{c-fb}(k+1), x_{fb}(k+1)) - \Psi(I_{c-fb}(k+1), x_{fb}(k))}{\Delta t}$$

[0030]   In the alternative, back emf can be estimated for both the open and close coils as:

$$e = \frac{\Psi_4 - \Psi_1}{\Delta t}$$

where $\Psi_4 = \Psi(I_{c-fb}(k), x_{fb}(k+1))$, or $\Psi_4(I_{o-fb}(k), X_{fb}(k+1))$. When the sampling period, Δt, is small enough, the two estimates should be very close.

[0031]   As discussed above, the output from the back emf estimator 220 is summed 218 to produce the desired voltages that will be communicated to the controller for the actuator.

[0032]   In another embodiment of the present invention an initialization method is provided. It is particularly applicable to the current-command method 100 and will be described herein in conjunction therewith. However, it is possible to apply to the initialization method to the other control methods as well. The only difference is that in the back emf control method, the current regulation will be accomplished through software control in the controller, whereas for the current-command method, a current regulator accomplishes current regulation in the power stage.

[0033]   Referring to Figure 6 there is shown the position response 302 of an armature to the initialization method of the present invention. It is shown that the armature oscillates from a low level to the desired initialization level over a predetermined period of time. In the prior art, it is typical to apply a very high current to the armature in order to initialize the armature position. It is also known to use both the opening and closing coils to accomplish initialization.
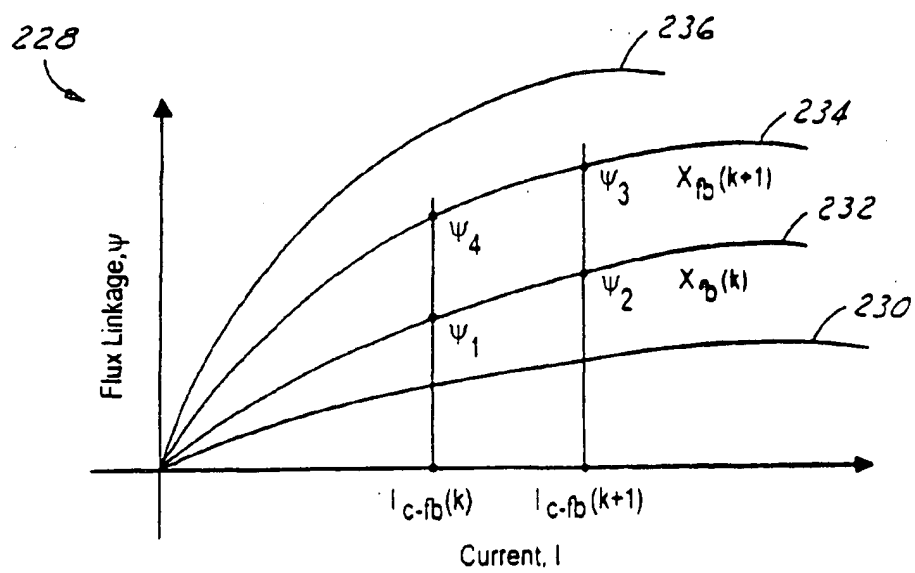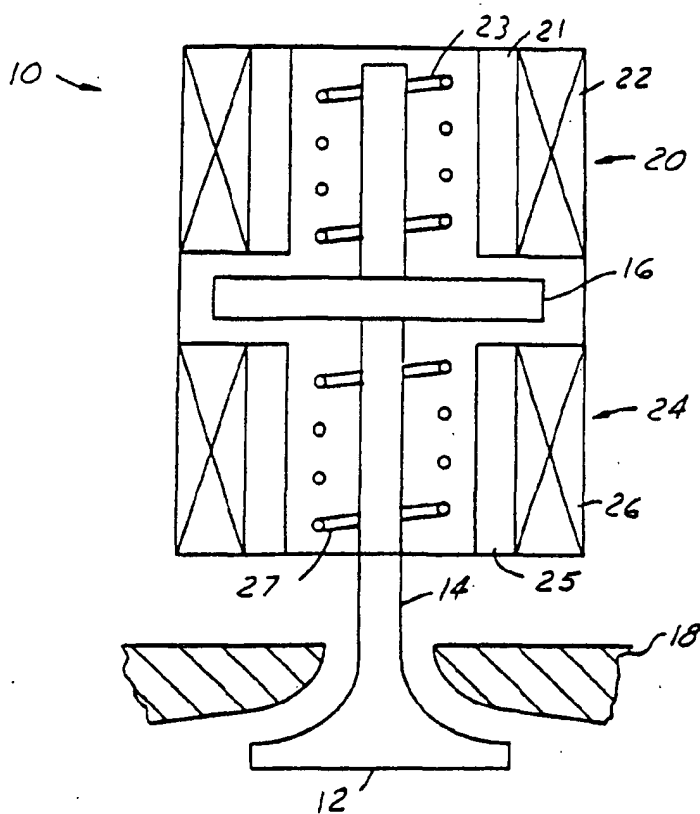
[0034]   In the method of the present invention, only one coil is used to accomplish initialization. The armature has a natural frequency that is enhanced by the application of pulses, as shown graphically 304 in Figure 7, at predetermined intervals during the oscillation cycle, in order to enhance the amplitude of the oscillation. Working in conjunction with the natural frequency of the armature, it is possible to apply low voltage pulses, which means lower current, during the initialization process.

[0035]   In the preferred embodiment, only the closing coil is used for the initialization of the actuator. Typically, the closing coil requires higher power rating to move the armature because the armature is held at the closed position at about 75% duty cycle. Therefore, the closing coil is typically the larger of the two coils in the actuator. By applying the initialization method of the present invention, the opening coil, and the driving circuit associated therewith, can be significantly reduced in size and therefore, significant cost and space savings will be realized. It should be noted that while the preferred embodiment is to apply the initialization method 400 to the closing coil, similar results are accomplished when the method is applied to the opening coil instead. However, the benefits to space and weight savings are not as significant as when the method is applied to the larger closing coil.

[0036]   The invention covers all alternatives, modifications, and equivalents, as may be included within the spirit and scope of the appended claims.

Claims

1. A method for generating a current command to a controller for an electromagnetic valve actuator system having a controller, a power stage and an electromagnetic actuator having an armature therein, said method comprising the steps of:

   supplying said controller with a feedback signal from the position of the armature, a reference waveform representing a desired movement for the armature, and a spring force constant;
   processing said position feedback signal, said reference waveform and said spring coefficient to generate a desired force, F_{em};
   dividing said desired force, F_{em} into a closing force component, F_{em_c}, and an opening force component, F_{em_o};
   individually processing each component with a fixed constant to produce a closing current command, Ic_cmd and an opening current command, Io_cmd; and
   communicating said current commands from the controller to the power stage for generating the current necessary to move the armature.

2. The method as claimed in claim 1 wherein said step of processing said position feedback signal, said reference waveform and said spring force constant further comprises the steps of:

   summing said position feedback signal, and said reference waveform;
   processing said summation with a proportional-integral-derivative controller to produce a force, F_A, necessary to move the armature; and
   processing said reference waveform to produce an estimate of an accelerated force, F_B, due to the mass of the armature;
   combining said spring coefficient, said accelerated force, F_B, and said force, F_A, to produce said desired force, F_{em}

3. The method as claimed in claim 1 wherein said step of individually processing each force component further comprises the step of generating said fixed constant by mathematically modeling movement of the armature.

4. A method for generating a desired voltage command for an electromagnetic valve actuator system having a controller, a power stage and an electromagnetic actuator having an armature therein and opposing opening and closing solenoids, said method comprising the steps of:

   summing a position feedback signal for the armature and a reference waveform representing a desired armature motion;
   processing said summation by a proportional-integral controller to obtain a current signal;
   dividing said current signal into a closing current component and an opening current component;
   summing said closing current component with a closing current feedback signal;
   processing said summed signal by a proportional-integral controller to obtain voltage signal;
   combining said voltage signal with an estimated back emf for the closing solenoid to obtain a desired closing voltage signal;
   summing said opening current component with an opening current feedback signal;
   processing said summed signal by a proportional-integral controller to obtain a voltage signal;
   combining said voltage signal with an estimated back emf for the opening solenoid to obtain a desired opening voltage signal; and
   communicating said closing voltage signal and said opening voltage signal to the power stage.

5. The method as claimed in claim 4 wherein said step of dividing said current signal further comprises dividing said current signal through software generated current regulation.

6. The method as claimed in claim 4 wherein said steps of estimating back emf for the opening and closing solenoids further comprises:

   storing a flux linkage, Ψ, for one of the solenoids as a function of armature position and coil current;
   sampling said flux linkage for at least two points in time; and
   estimating a back emf as a function of flux linkage, Ψ, and a sampling period, Δt.

7. A method for initializing an actuator valve having an armature having a natural oscillation frequency, an opening solenoid and an opposing closing solenoid, said method comprising the step of applying a series of low voltage pulses to one of said solenoids, said series of low voltage pulses being applied at predetermined intervals corresponding to the natural frequency of the armature.

8. The method as claimed in claim 7 wherein said series of low voltage pulses is applied to the closing solenoid.
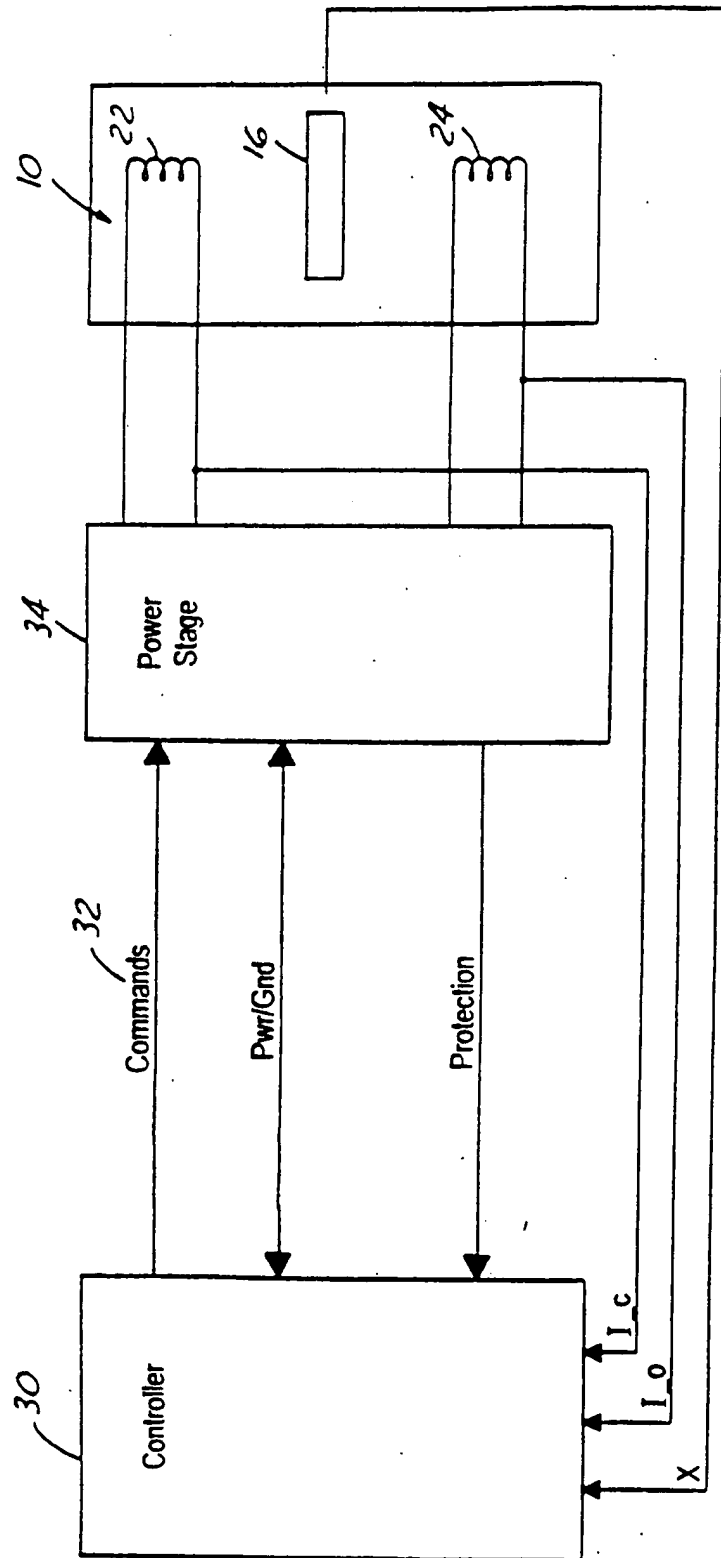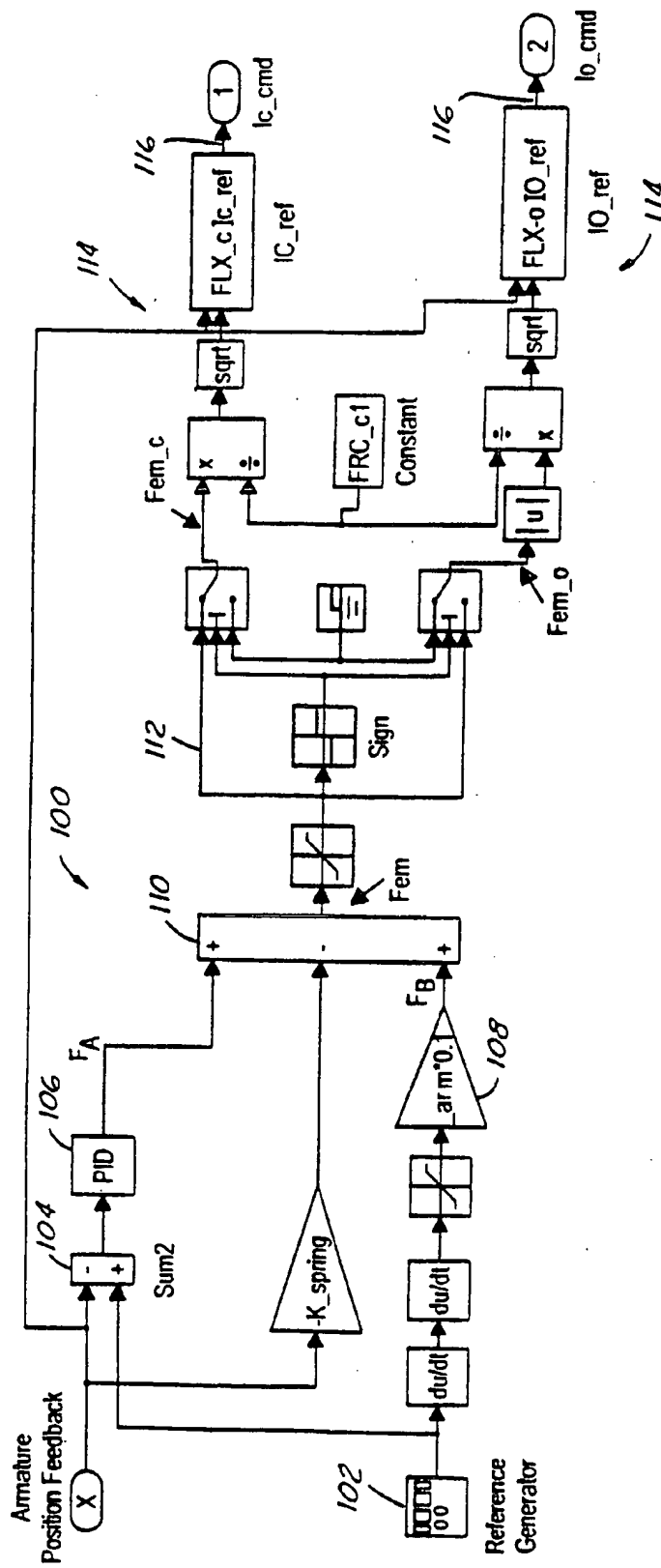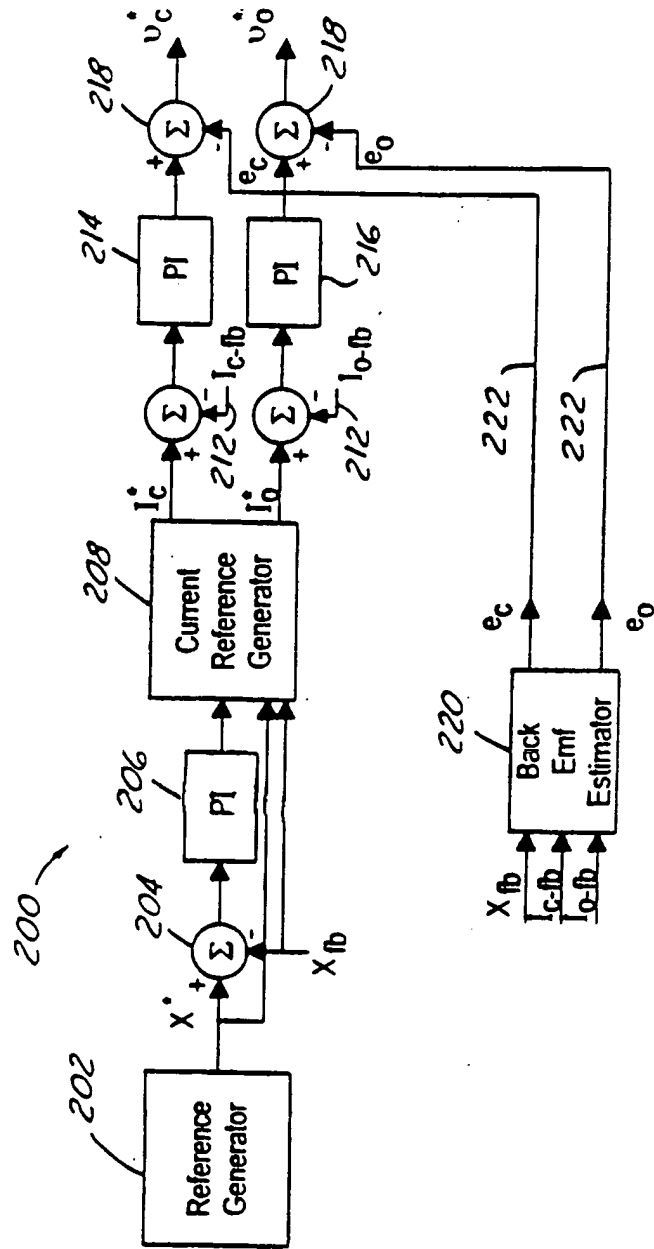
FIG. 1

FIG. 5

FIG. 2

FIG. 3

FIG. 4

FIG. 6

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Armature Displacement

Closed   0   Open

Time (s)

0.015 0.01 0.015 0.02 0.025 0.03 0.035 0.04 0.045 0.05

FIG. 7

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Voltage (V)

Time (ms)

0.015 0.01 0.015 0.02 0.025 0.03 0.035 0.04 0.045 0.05